





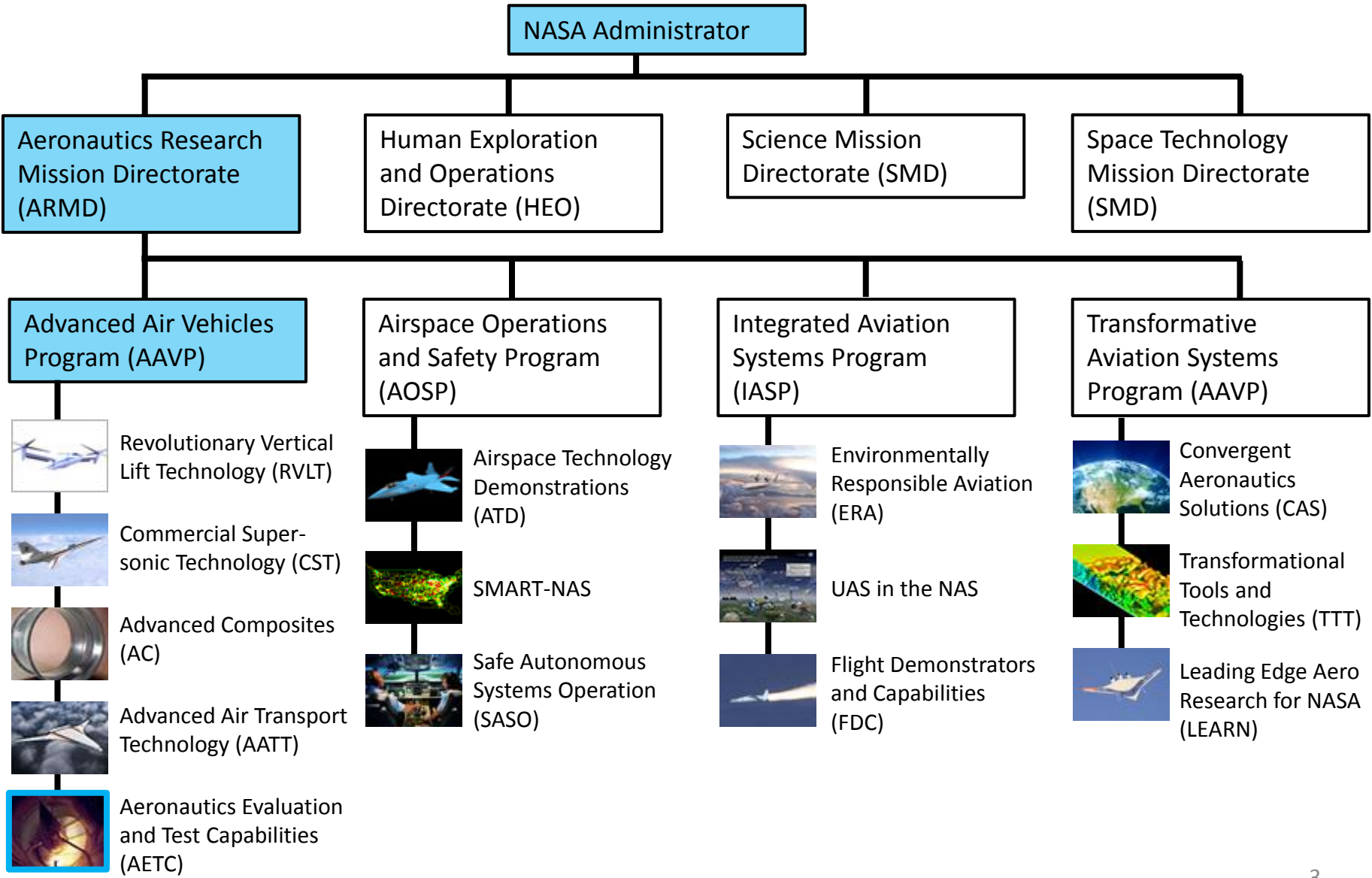
# Outline

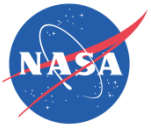


- Introduction to the Aeronautics Evaluation and Test Capability (AETC)
  - AETC position within NASA Aeronautics Organization
  - Composition and Role of AETC
- Overview of the NASA AETC Facilities
- New capabilities under development
- Conclusion: Addressing the needs of the T&E community



# AETC Wind Tunnels within NASA

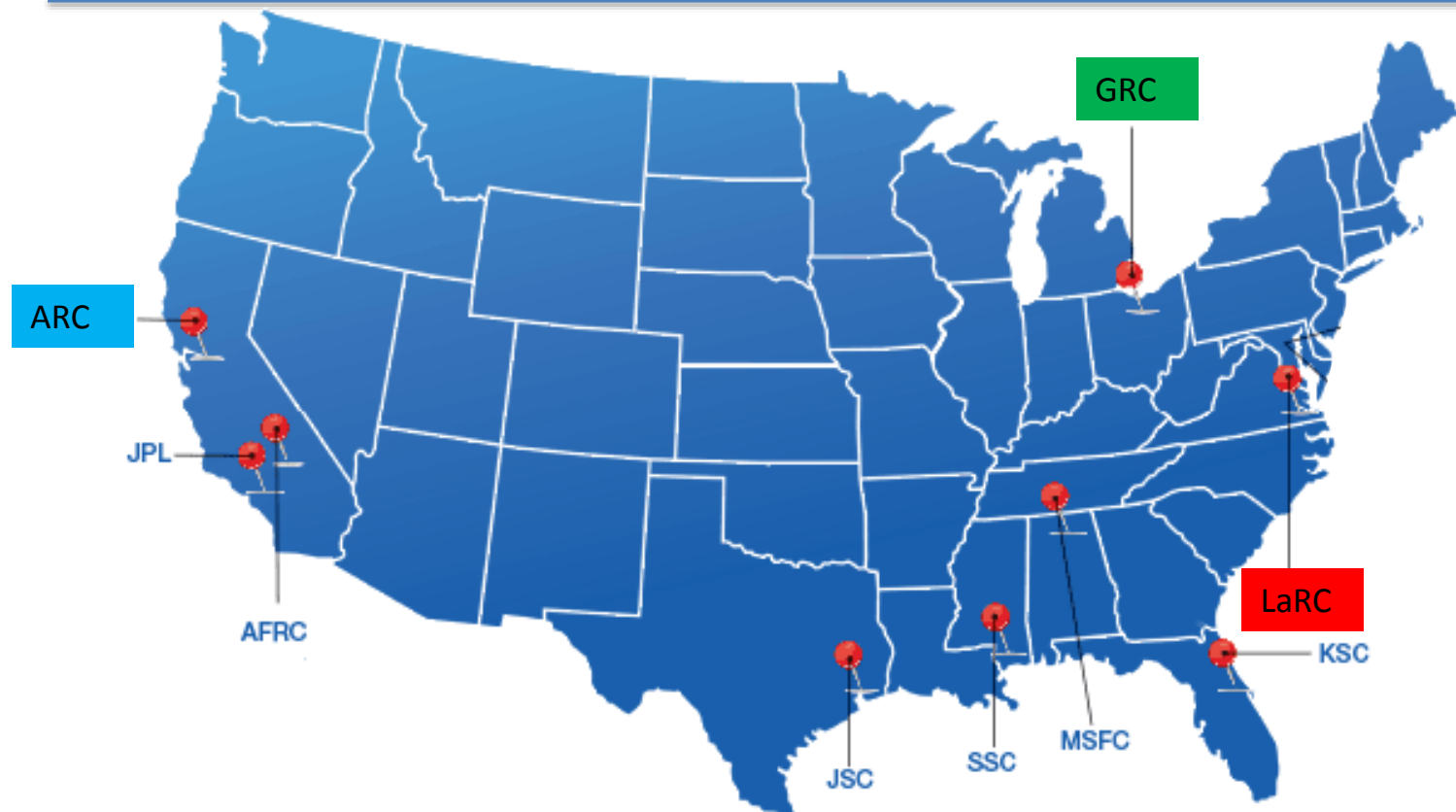




# AETC Role and Organization

- AETC's role is to preserve and enhance the ground test capabilities needed to achieve ARMD's missions.
- AETC invests in workforce and assets needed to help the facilities support ARMD, while the facilities themselves are owned and operated by their respective centers.
- AETC is divided into four elements:
  - Operations: Direct funding to support key labor and procurement needs while maintaining stable and competitive rates to customers.
  - Maintenance: Funds directed to maintain physical plant to ensure current operations and minimize risk for the future.
  - Capability Advancement: Handles large scale investments in facility physical plant, controls, and data systems.
  - Test Technology: Funds small-scale “pilot” projects to bring new test capabilities, especially measurement systems, into the facilities.

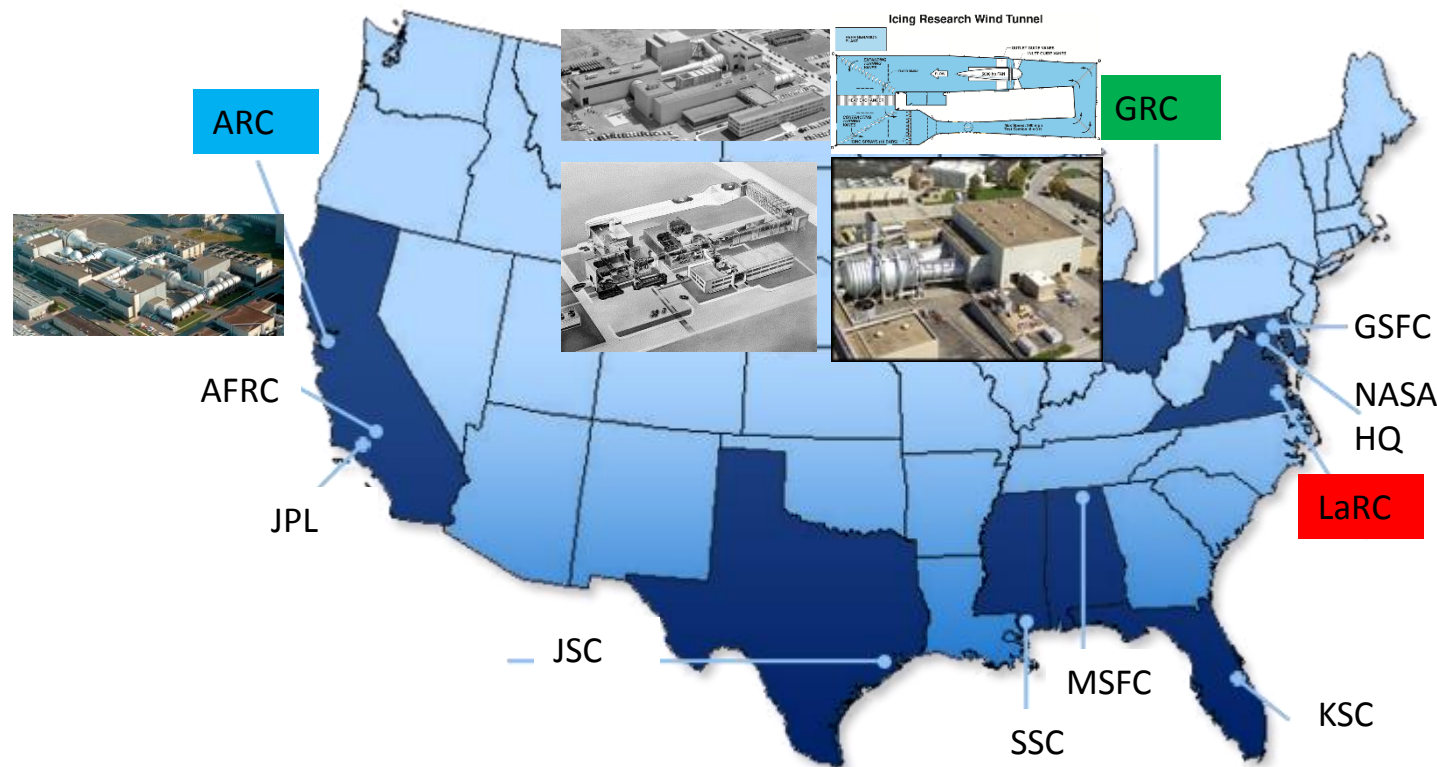
# AETC Facility Locations and Summary



ARC	11x11	General purpose transonic	GRC	IRT	Subsonic icing
ARC	9x7	General purpose supersonic	GRC	PSL	High altitude engine test cell with icing
GRC	10x10	Supersonic propulsion/aerodynamic	LaRC	NTF	Transonic full-scale Reynolds number
GRC	8x6	Supersonic propulsion/aerodynamic	LaRC	TDT	Transonic aeroelastic
GRC	9x15	Subsonic propulsion & acoustics	LaRC	14x22	Subsonic general purpose



# AETC Facility Locations and Summary

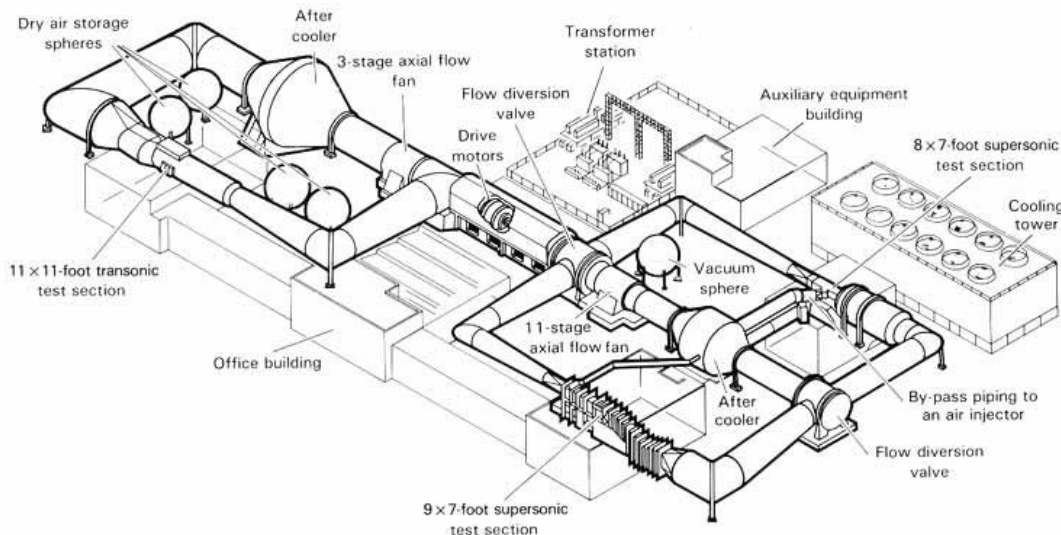
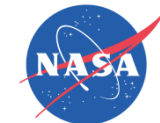


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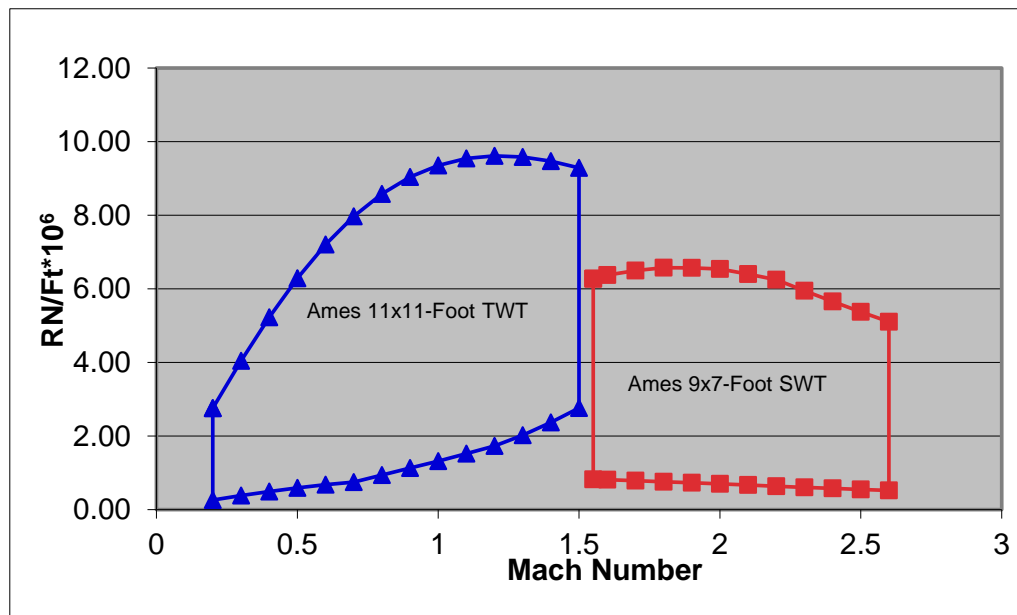




# 11x11 and 9x7 (Ames)



- Completed in 1956 in response to government & industry need for high Re, transonic/supersonic production testing capability. Major refurbishment in 1995.
- 4 x 64,000 HP motors drive either 11x11-ft transonic or 9x7-ft supersonic test sections.
- Averaged 1640 hrs/yr usage over past eight years.
- 1/3 time was NASA, remainder was industry and DoD.
- Significant features:
  - Workhorse tunnel for complex high Reynolds tests
  - Good optical access for unusual instrumentation techniques (PSP, PIV, schlieren, BOS)
  - 3000 channels unsteady data
  - 3000 psi air available up to 80 lbm/s.

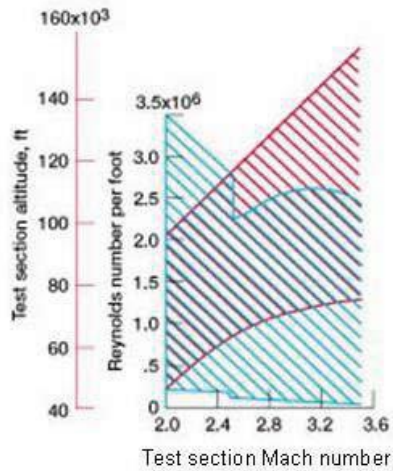




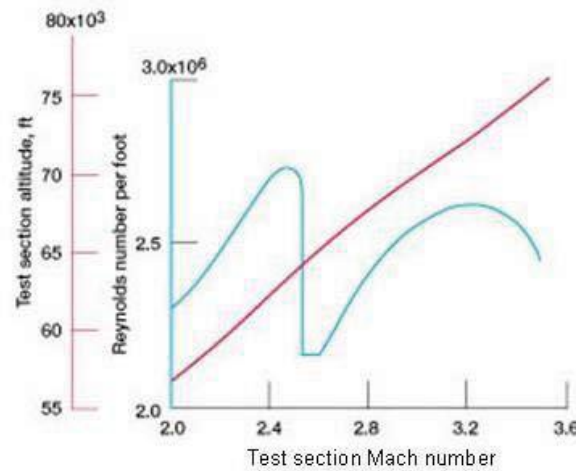
# 10x10 Wind Tunnel (Glenn)



- Completed in 1955 to provide high Re, supersonic propulsion testing capability.
- 288,750 total horsepower
  - 4 x 41,500 HP motors drive 8-stage main compressor for flow up to  $M=2.6$
  - 3 x 41,500 motors drive 10-stage secondary compressor for flow up to  $M=3.5$ .
- Operates in subsonic (up to  $M=0.4$ ) or supersonic ( $M=2.0$ - $3.5$ ) mode. Can achieve up to  $M=4.1$  locally.
- Standard altitude simulation range is 50,000 – 150,000 ft but can go up to 200,000 ft.
- Temperature range up to  $680^{\circ}\text{F}$  to simulate  $M=3.1$  stagnation temperature.
- Switches between closed loop mode for aerodynamic testing and open loop mode for propulsion testing.
- Plumbed for kerosene,  $\text{LH}_2$ ,  $\text{LOX}$  delivery, as well as high pressure air up to 2600 psi.
- Optical access for BOS, PIV, focusing schlieren and other techniques.
- Low disturbance environment suitable for laminar flow testing.



(a) Aerodynamic cycle (closed loop).



(b) Propulsion cycle (open loop).





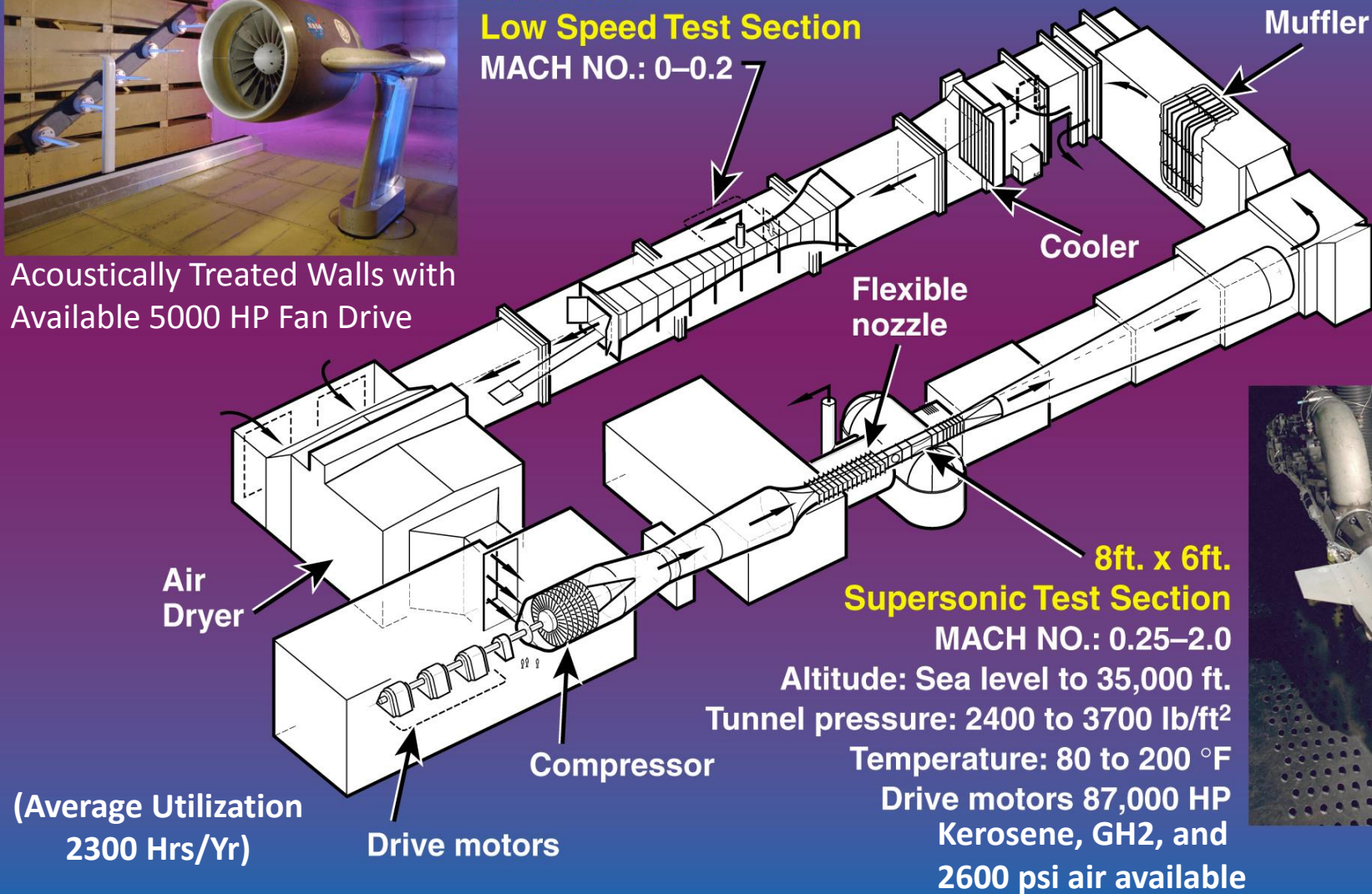
# 8x6 and 9x15 Wind Tunnels (Glenn)



Acoustically Treated Walls with Available 5000 HP Fan Drive

**9ft. x 15ft.  
Low Speed Test Section**  
MACH NO.: 0–0.2

Operating mode: Aerodynamic–Closed loop  
Propulsion–Open loop



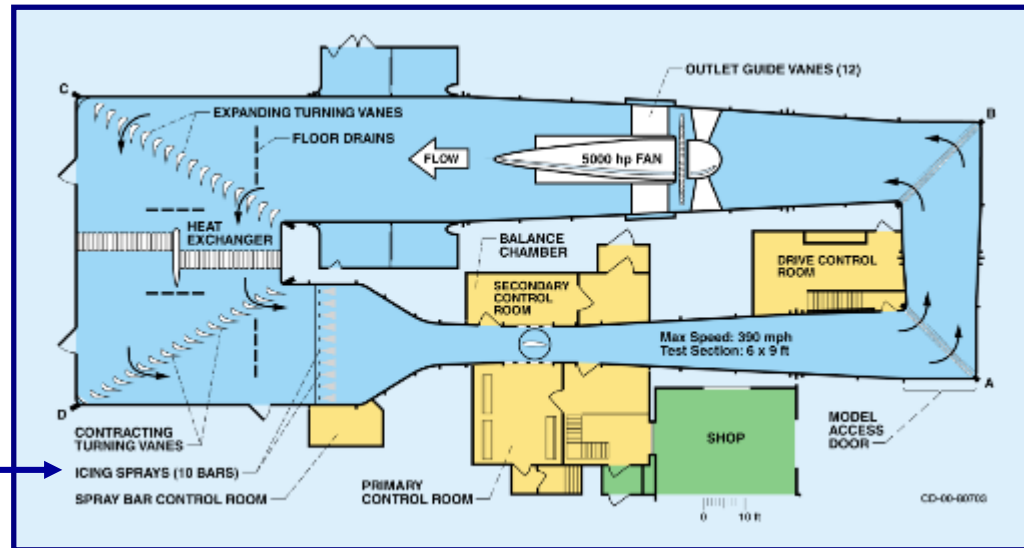


# Icing Research Tunnel (Glenn)



## Capabilities

- 2100 ton refrigerator allows replication of icing certification standards contained in FAR part 25, appendix C.
- Extensively used by industry to show compliance with FAA icing standards.
- Average usage 1580 hrs/yr primarily for industry customers.



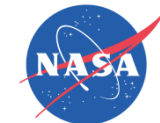
## Performance

- Test Section 6 ft tall x 9 ft wide and 20 ft long.
- Air speed from 50 to 300 kt.
- Air temperatures as low as  $-40^{\circ}\text{C}$ .
- Drop size 15 to 50  $\mu\text{m}$  MVD (Appendix C) + SLD up to  $\approx 250 \mu\text{m}$ .
- Liquid Water Content (LWC) controllable between 0.2 and 3.0  $\text{g/m}^3$  (LWC depends on speed and MVD).
- Centralized exhaust system flow rate of 3 to 85 lb/s for simulating engine airflow.
- Hot bleed air simulation up to 1 lb/s.





# Propulsion Systems Laboratory (Glenn)



## Combustion Air

- 480 lbs/sec at ambient and 55 psia
- 380 lbs/sec at ambient and 165 psia
- 76 lbs/sec at ambient and 450 psia
- Max inlet temp 875°F
- Min inlet temp -50°F

## Exhaust

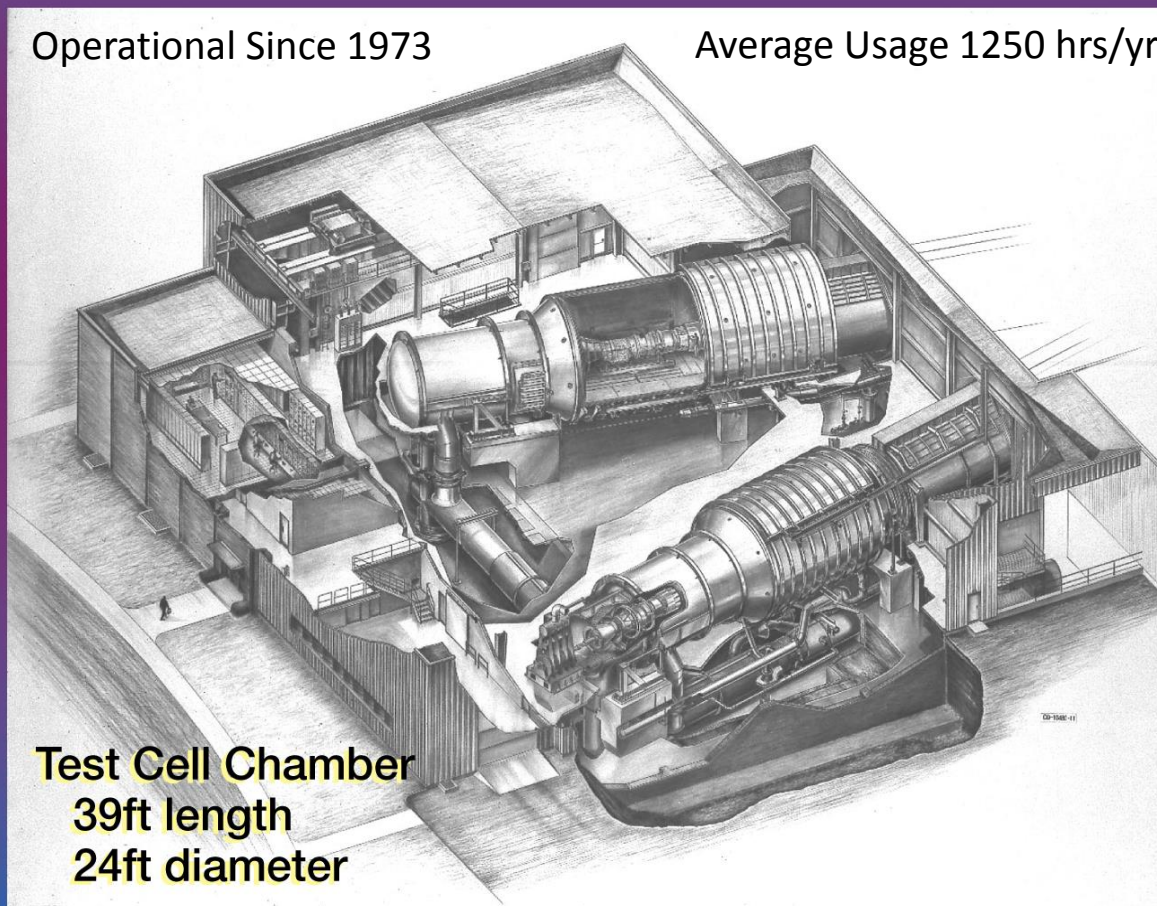
- Max flow 750 lbs/sec at SLS ~ sea level standard
- Max altitude 70,000 ft +

## Data Acquisition

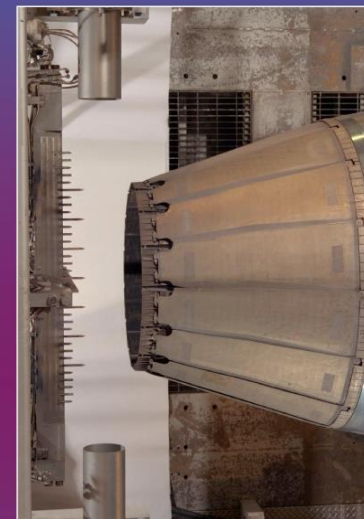
- 1248 Channels for steady state data
- 256 Channels for transient data

Operational Since 1973

Average Usage 1250 hrs/yr



**Test Cell Chamber**  
39ft length  
24ft diameter

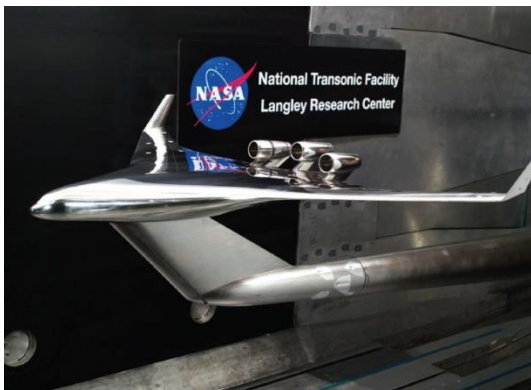




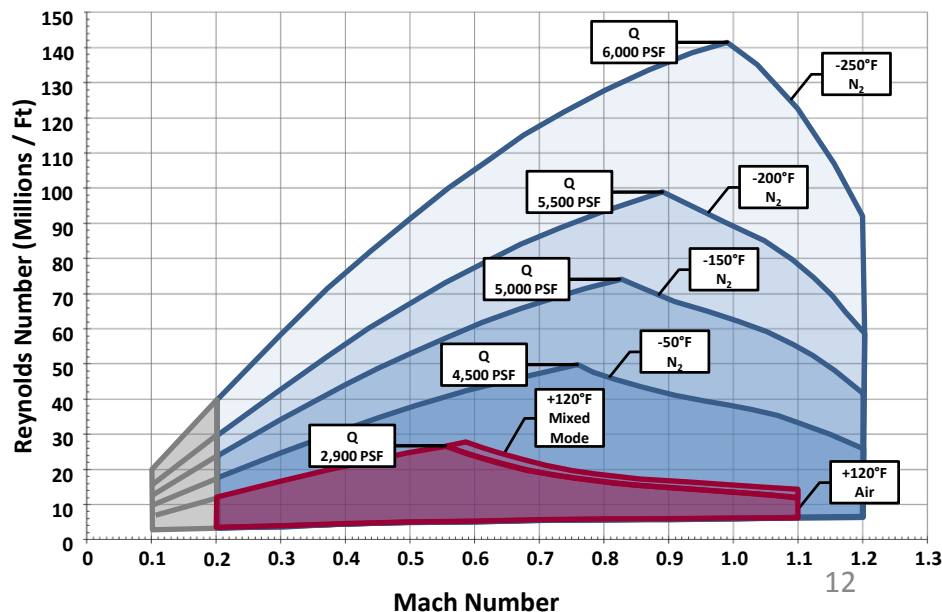
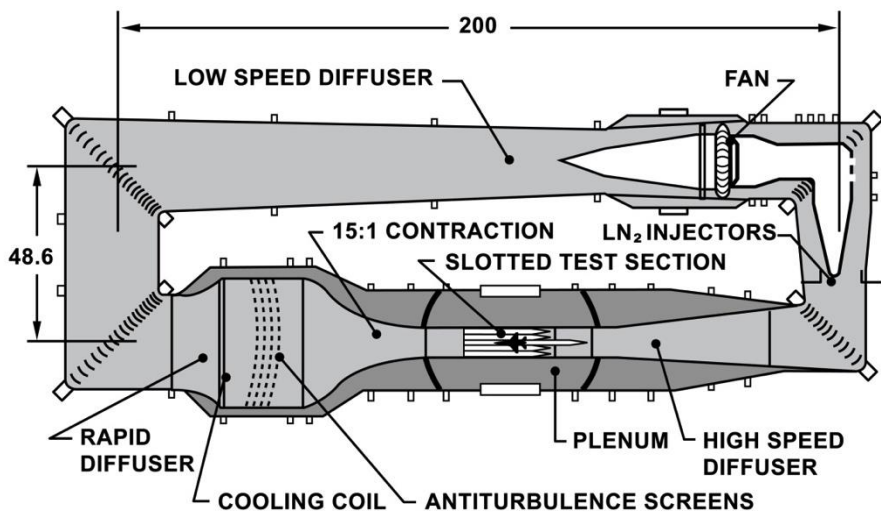
# National Transonic Facility (Langley)



- Came on-line in 1983 to provide full-scale Reynolds number testing capability by operating with air or cryogenic nitrogen gas.
- Active flow control/propulsion integration capability.
- High-speed cruise and low-speed high-lift performance testing.



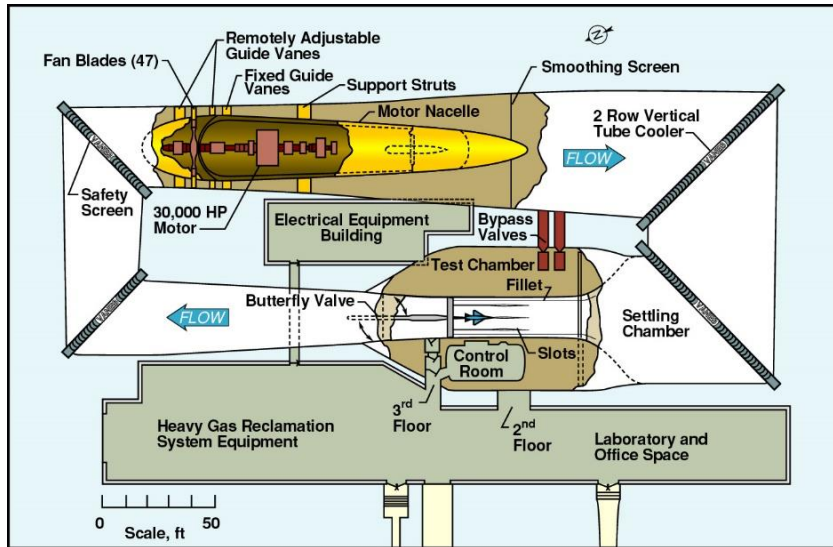
Test Section	8.2 x 8.2 x 25 Feet ( 2.5 x 2.5 x 7.6 meters)	
Pressure	14.7 to 133 psia; 1 to 9.0 atm.; 1.01 to 9.1 bar	
	<b>Air Operations</b>	<b>N<sub>2</sub> Operations</b>
Mach No.	0.2 to 1.05	0.2 to 1.20
Reynolds No. Max	20x10 <sup>6</sup> / ft (65x10 <sup>6</sup> / m)	145x10 <sup>6</sup> / ft (475x10 <sup>6</sup> / m)
Temperature	90° to 150°F (32° to 65°C)	-50° to -250°F (-45° to -157°C)



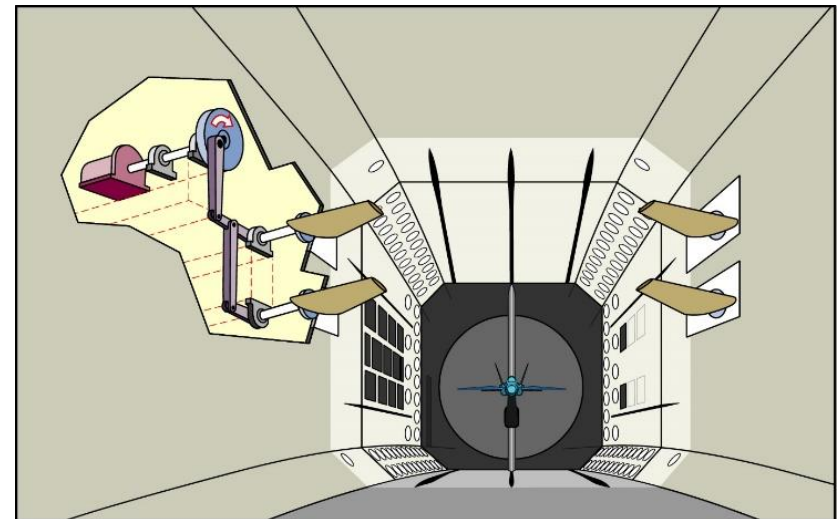
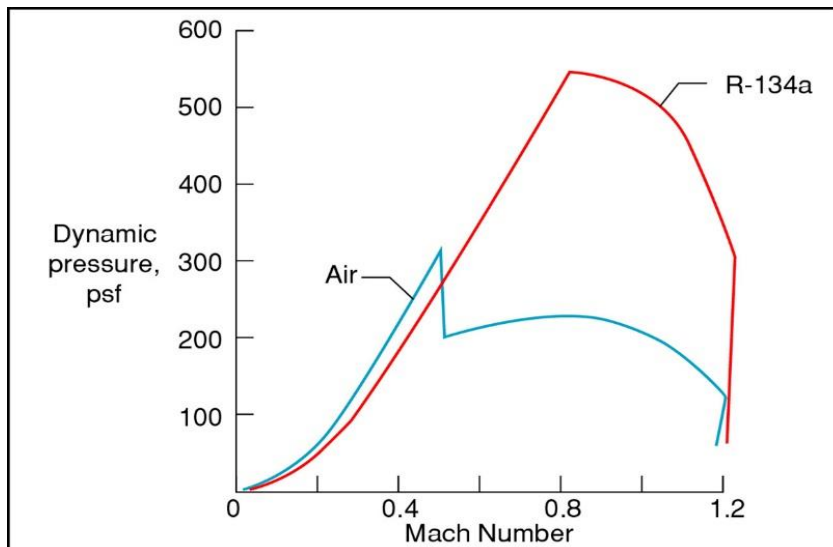




# Transonic Dynamics Tunnel (Langley)



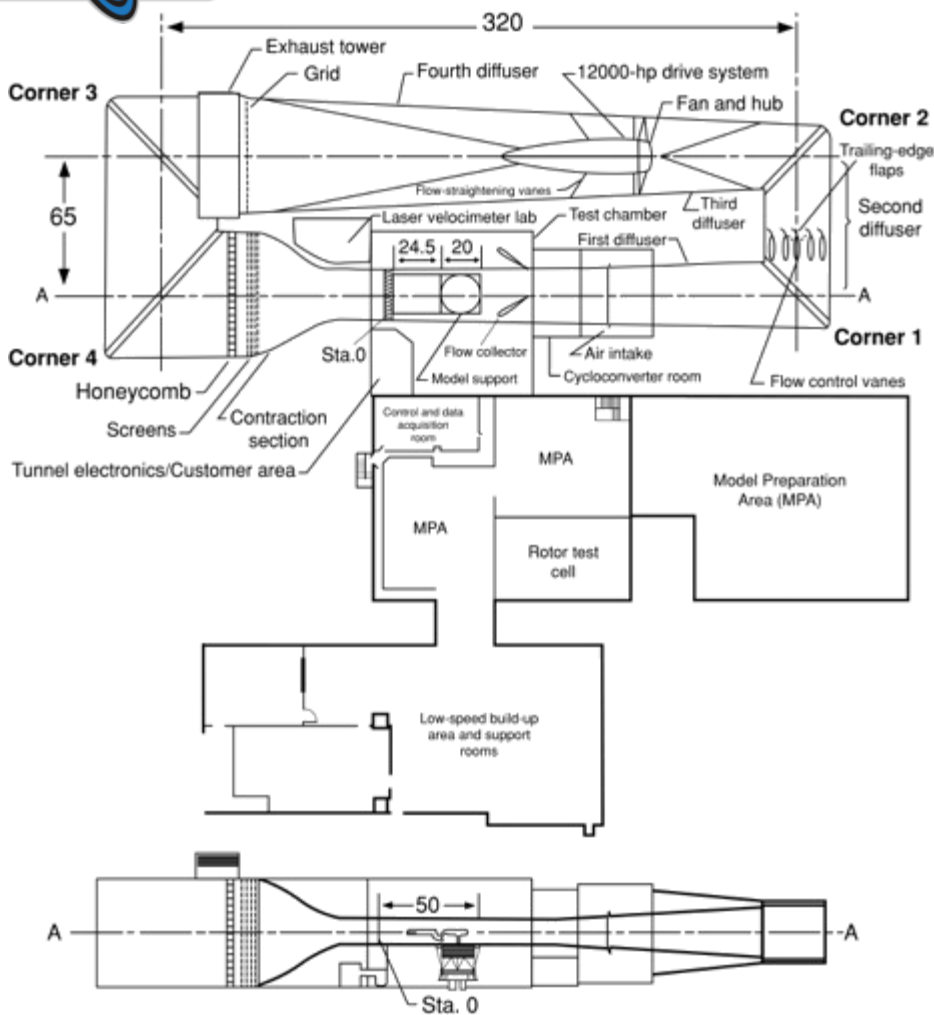
- Came on-line in 1960 to provide large scale transonic aeroelastic testing capability.
- Operates with either air or R-134a heavy gas.
- Averaged 1015 hrs/yr usage over past eight years. (1/3 NASA – remainder industry & DoD.)
- Significant features:
  - Excellent model visibility from control room
  - Safety screens for fan protection
  - Rapid tunnel shutdown for model safety
  - Airstream oscillator (gust generating) system







# 14-by 22-Foot Subsonic Tunnel (Langley)



## Characteristics:

- Closed circuit, single return, atmospheric
- Closed and open test section configurations
- Speed, foot per second..... 348 (closed), 283 (open)
- Reynolds number, per foot..... 0 to  $2.2 \times 10^6$
- Test gas..... Air
- Test section size, feet..... 14.5 x 21.75
- Test Section Length, feet..... 50
- Drive power, horsepower..... 12000 continuous
- Model build-up in large Model Preparation Areas
- Model support on different Model Carts



# New Capabilities

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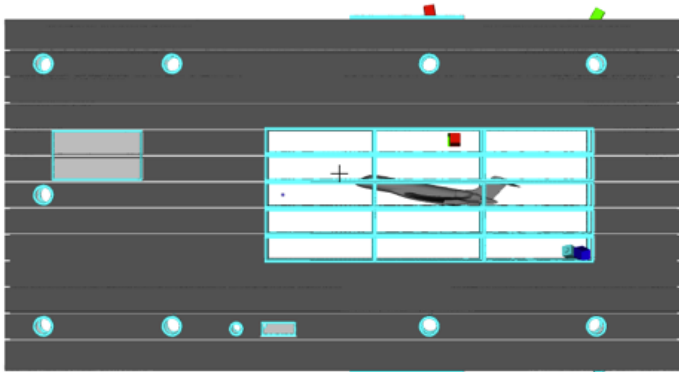
- Optical Test Section of Tomorrow for 11x11 and 9x7
- Improved Acoustic Treatment for 9x15
- Improved Icing Capability for IRT and PSL
- Other Improvements



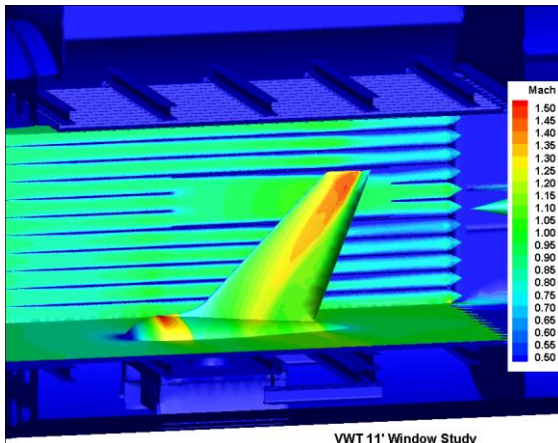
# Optical Test Section of Tomorrow



- Greatly enhance optical access for instruments in 11x11 and 9x7 wind tunnels at ARC, by cutting new window ports in test section walls and by enlarging existing windows.
- Enhance access to 11x11 plenum area (for instrument installation) with new doors in the pressure shell.
- Upgrade electrical and data wiring within and around the test sections to allow more instruments to be accommodated.

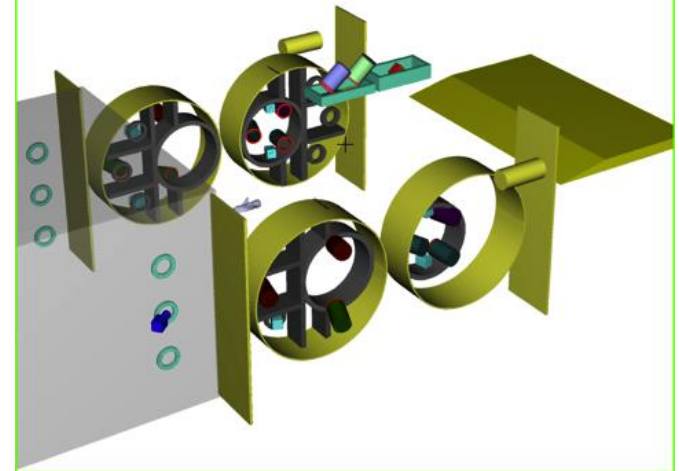


Sketch showing new porthole windows in 11x11.



CFD simulation showing flow in 11x11 with modified slot geometry due to presence of new larger windows.

Optical planning simulation showing new and modified window locations in 9x7.





# 9x15 Acoustic Mods



- Current acoustic treatment of the 9x15 can be improved, allowing more precise measurements of propulsion system sound levels.
- Project has identified five areas in the tunnel test section and circuit where acoustic treatments could efficiently reduce noise.
- Currently developing candidate designs for all five acoustic treatments. Will implement as many treatments as possible given funding level – ideally all five.

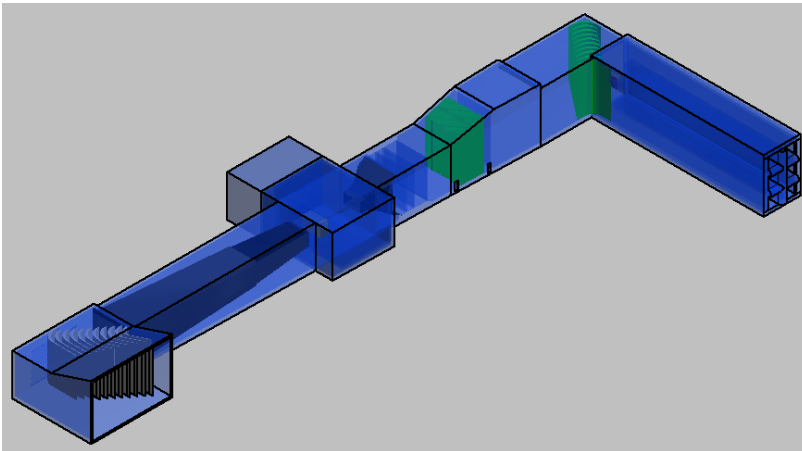


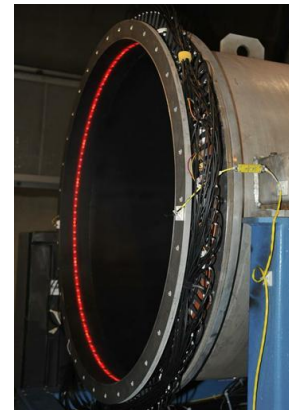
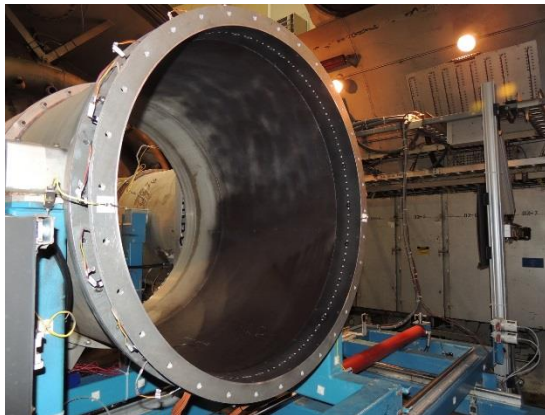
Diagram showing portion of 9x15 circuit, with some areas for acoustic treatment highlighted.



# SLD/Ice Crystal Mods for IRT/PSL



- New FAA requirements in place as of January 2015 amend airworthiness standards for icing certifications with regard to Supercooled Large Droplets and Ice Crystal conditions.
- NASA is enhancing the capabilities of the IRT and PSL to both generate SLD/Ice Crystal conditions and to measure such conditions accurately.
- Icing work includes new instruments for measuring SLDs and ice crystals, as well as modifications to the IRT and PSL spray systems.



Laser tomography system for measuring water droplet density in PSL





# Other Improvements



- Improve capability for powered testing in NTF.
  - New high pressure air system
  - Investigate transferring power across cryogenic balance for fan simulators.
- Upgraded data systems for 14x22, TST, ARC 11x11 and 9x7.
- Heat exchanger for 14x22 to allow more accurate flow measurements.
- “Clean” particle seeding for optical measurement systems in ARC 11x11, 14x22, other facilities.
- New blades for 11x11 three-stage compressor. Replace current Al blades with new Al, steel, or composite blades for improved life and enhancement of facility efficiency and operating envelope.
- Improved optical measurement techniques at all facilities
  - Background-Oriented Schlieren
  - Unsteady PSP
  - High Speed Shadowgraph
  - IR Thermography
  - Photogrammetry



# Conclusion: AETC Role in T&E



- AETC facility usage by broad category
  - NASA research.
  - Development of commercial and military aircraft.
  - Development of NASA spacecraft (launch vehicles and crew capsules).
  - Test and evaluation for DoD and commercial customers.
- AETC facility experience in Test and Evaluation
  - IRT & PSL used for FAA certification for icing.
  - 11x11 used by Navy.
- AETC facility advantages for T&E
  - Provide high quality data
  - Large number of specialized capabilities
  - Generally high availability



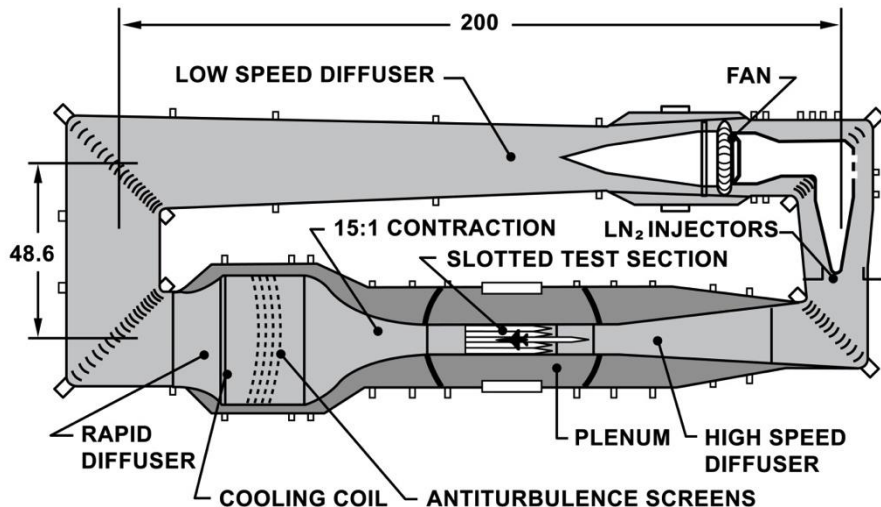
# Backup Slides

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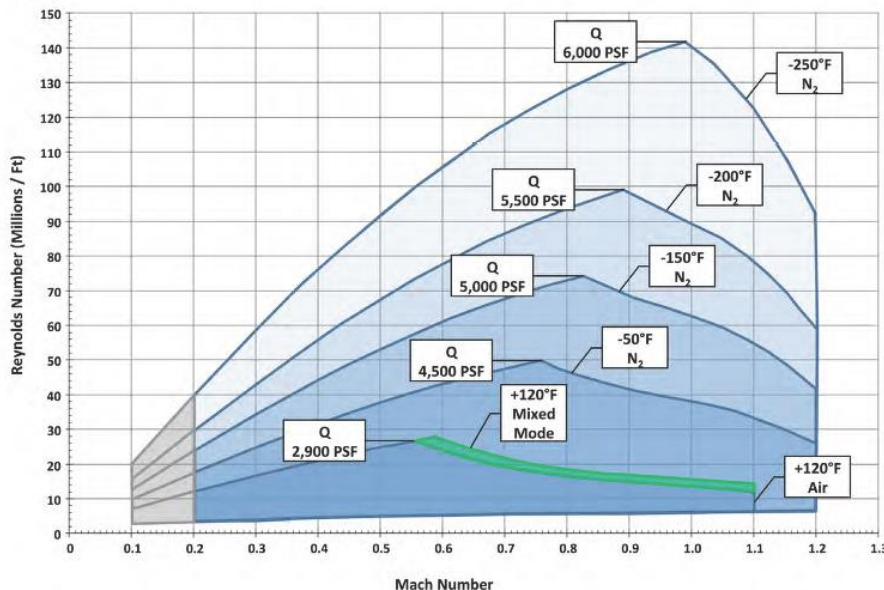




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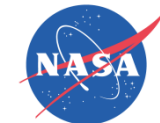


- Came on-line in 1983 to provide full-scale Reynolds number testing capability.
- Operation with cryogenic nitrogen gas allow Reynolds numbers up to  $140 \times 10^6/\text{ft}$ .
- Averaged 590 hrs/yr usage over past eight years.
- 2/3 time was NASA, remainder was industry and DoD.
- Significant features:
  - Highest Re in the world.
  - Only US wind tunnel able to achieve full-scale Re for large aircraft.
  - Air mode operation allows comparison of pressure/Re effects and higher productivity when only moderate Re (up to  $25 \times 10^6/\text{ft}$ ) is needed.
  - Independent Mach, Re and Dynamic Pressure control.
  - Active flow control/propulsion integration capability.
  - High-speed cruise and low-speed high-lift performance testing.





# AETC Facility Summary

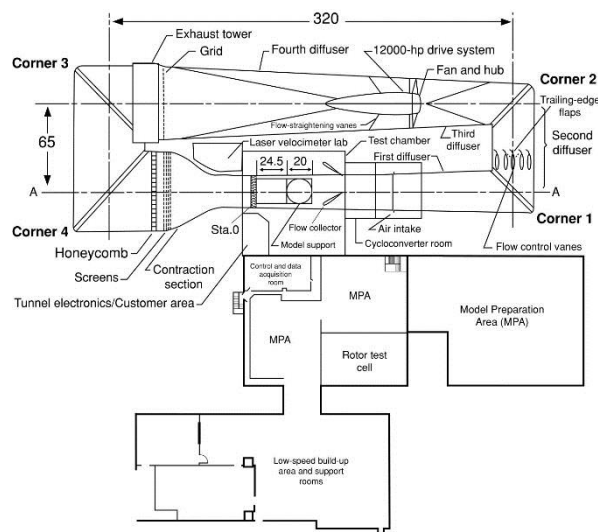


Name	Mach	Special Features
11x11	0.0 – 1.4	General purpose
9x7	1.5 – 2.5	General purpose
10x10	0.0 – 0.4, 2.0 – 3.5	Propulsion/Aerodynamic
8x6	0.25 – 2.0	Propulsion/Aerodynamic
9x15	0.0 – 0.2	Propulsion, acoustically-treated test section
IRT	0.0 – 0.45	Icing
PSL	0.0 – 4.0	High altitude engine cell, icing capability
NTF	0.2 – 1.2	Full scale flight Reynolds number
TDT	0.0 – 1.2	Aeroelasticity
14x22	0.0 – 0.2	¾ open test section for acoustics, rotorcraft





# 14-by 22-Foot Subsonic Tunnel (Langley)



- Came on-line in 1970 in response to need for facilities suited to V/STOL aircraft research.
- Initially named as the V/STOL Transition Tunnel, later changed to the 4 by 7-Meter Low Speed Tunnel (1982), and finally renamed to the 14-by 22-Foot Subsonic Tunnel (1985)
- Major renovations in 1985, 1999, 2001, and 2012
- Averaged 870 hrs/yr usage over past eight years.
- Significant features:
  - $\frac{3}{4}$  open jet capability (walls and ceiling removed) capability
  - Model Preparation Area with 12 build-up sites
  - Model support systems on 4 large movable Model Carts
  - Acoustic testing capability
  - Rotorcraft testing in hover (Rotor Test Cell) and forward flight (14x22)
  - Tether free-flight
  - Forced oscillation
  - Propulsion simulation

